



Experimental and Numerical Analysis of Wind Turbine

T.Mothilal¹, M.D.Raj Kamal^{2*}, S.Kaliappan¹, G.Jagadeesh Babu³, S.Socrates²

¹Associate Professor, Department of Mechanical Engg, Velammal Institute of Technology, Chennai, India

²Assistant Professor, Department of Mechanical Engg, Velammal Institute of Technology, Chennai, India.

³Student, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, India

*Corresponding author E-Mail Id: kamalaerodynamics@gmail.com

ABSTRACT

The objective of this Paper is to design and build a self-starting vertical axis wind turbine that is capable of producing power in real world situations. The design of the turbine will include exploration of various self-starting options, as well as the construction of both mode land full-scale turbines. The full-scale turbine will be designed such that it can be connected to a generator and a torque transducer to measure the output power, torque and rotational speed of the turbine. The design will also allow for data collection regarding the effects of blade pitch angles. Here compare both experimental and simulation analysis by using CFD and As a result of the engineering analysis carried out for the NACA 0012 and it had been designed in design software Catia and the flow analysis was carried out in CFD by using Fluent and CFX software.

Keywords; *CFD, Turbine, rotational speed, CFX, FLUENT*

1. INTRODUCTION

The main objective of the project is doing improve the output of the wind power generation produce electric power using a vertical axis wind turbine, Currently, horizontal axis wind turbines (HAWT) dominate the wind Energy market due totheir largesize and highpower generation characteristics. However, vertical axis wind turbines (VAWT) are capable of producing a lot of power and offer many advantages. The mechanical power generation equipment can be located at ground level, which makes for easy maintenance.

2. INTRODUCTION TO CFD

CFD is a technique of replacing Partial Differential Equations governing the fluid flow by a set of algebraic equations and solving them using a digital computer. Any fluid flow in the universe is governed by a set of equations. The equations are the governing equations,

- Continuity Equation.
- Momentum Equation.
- Energy Equation.

Governing equations in partial differential form

2.1. Continuity Equation

The continuity equation in algebraic form is given as

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

The continuity equation in integral form is given as,

$$\frac{\partial}{\partial t} \rho dv + \rho V \cdot dS = 0$$

The continuity equation in Partial Differential Form is given as,

$$\partial \rho / \partial t + \nabla \cdot \rho \mathbf{V} = 0$$

2.2. Momentum Equation

$$\partial \rho \mathbf{V} / \partial t + \rho \mathbf{V} \cdot \nabla \mathbf{V} = - \nabla p + \rho \mathbf{f} + \mathbf{F}_{\text{viscous}}$$

2.3. Energy Equation

$$\rho \mathbf{V} \cdot \nabla e + \nabla \cdot (\rho e \mathbf{V}) = \rho \mathbf{f} \cdot \mathbf{V} + \mathbf{W}_{\text{viscous}}$$

3. DESIGN CONSTRUCTION OF VERTICAL AXIS WIND TURBINE

Turbines relying on drag, such as the anemometer and Savonius models, cannot spin faster than the wind blows and are thus limited to a TSR of less than 1. Other turbines, such as the Darrieus, rely on the lift to produce a positive torque. Lift type wind turbines can experience TSR as high as 6. This is possible because the natural wind is vector summed with the wind opposing the forward velocity of the airfoil. This combined velocity is known as the relative wind. The constant $16/27 = 0.593$ from equation [3] is referred to as the Betz coefficient. The Betz coefficient tells us that 59.3% of the power in the wind can be extracted in the case of an ideal turbine. However, an ideal turbine is a theoretical case. Turbine efficiencies in the range of 35-40% are very good, and this is the case for most large-scale turbines. It should also be noted that the pressure drop across the turbine blades is very small, around 0.02% of the ambient air pressure. This increases the velocity of the leeward air and subsequently the lift. Power coefficient (C_p) is defined as the ratio of the output power produced to the power available in the wind. Betz Limit: No wind turbine could convert more than 59.3% of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit and is the theoretical maximum coefficient of power for any wind turbine. The maximum value of C_p according to Betz limit is 59.3%.

For good turbines, it is in the range of 35-45%. The tip speed ratio (λ) for wind turbines is the ratio between the rotational speed of the tip of the blade and the actual velocity of the wind. High efficiency 3-blade-turbines have tip speed ratios, the total capacity of wind power on this earth that can be harnessed is about 72 TW. There are now many thousands of wind turbines operating in various parts of the world, with utility companies having a total capacity of 59,322 MW. The power generation by wind energy was about 94.1 GW in 2007 which makes up nearly 1% of the total power generated in the world. Globally, the long-term technical potential of wind energy is believed to be 5 times current global energy consumption or 40 times current electricity demand. This would require covering 12.7% of all land area with wind turbines. This land would have to be covered with 6 large wind turbines per square kilometer. Some 80 percent of the global wind power market is now centered in just four countries—which reflects the failure of most other nations to adopt supportive renewable energy policies. Future market growth will depend in large measure on whether additional countries make way for renewable energy sources as they reform their electricity industries.

4. WORKING OF VERTICAL AXIS WIND TURBINE

Lift and drag forces can be broken down into components that are perpendicular (thrust) and parallel (torque) to their path of travel at any instant. The torque is available to do full work, while the thrust is the force that must be supported by the turbine's structure. The coefficient of performance depends on wind speed, the rotational speed of the turbine and blade parameters such as pitch angle and angle of attack. The pitch angle for a HAWT is the angle between the blades motion and the chord line of the blade, whereas for a VAWT the pitch angle is between the line perpendicular to the blades motion and the chord line of the blade. The angle of

attack is the angle between the relative wind velocity and the centerline of the blade. For fixed pitch turbines, these angles do not change. The operating tip-speed ratio (TSR) for a Darrieus rotor lies between 4 and 6. This design TSR then determines the solidity, gear ratios, generator speeds, and structural design of the rotor. Using this TSR and the graph in figure 1.4, a value of the solidity is elected. As with the prop-type rotor, the solidity allows for the calculation of blade area. Solidity times the rotor frontal area gives the total blade area. Dividing the total blade area by the number of blades (usually 2 or 3) gives the individual blade area. The dimensions of the VAWT being built for this project are given in the output power, torque and rotational speed of the turbine. The design will also allow for data collection regarding the effects of blade pitch angles. The diameter (1200 mm) is larger than the height (1000 mm) to provide a longer chord length for the same solidity. This design selection provides an increased Reynolds number for the flow over the blades, and subsequently, increases the lift, the design of the turbine will include exploration of various self-starting options, as well as construction of both model and full-scale turbines. The full-scale turbine will be designed such that it can be connected to a generator and a torque transducer to measure.

4.1. Experimental Setup



Fig 1. Experimental Setup of Vertical Turbine

5. RESULT AND DISCUSSION OF SIMULATION ANALYSIS

Our work and the results obtained so far are very encouraging and reinforce the conviction that vertical axis wind energy conversion systems are practical and potentially very contributive to the production of clean renewable electricity from the wind even under less than ideal sitting conditions. It is hoped that they may be constructed used high-strength, low-weight materials for deployment in more developed nations and settings or with very low tech local materials and local skills in less developed countries. The discussion has to be done based on the Simulation Analysis using Fluent and CFX and Design had been done by using Catia.

5.1. Model

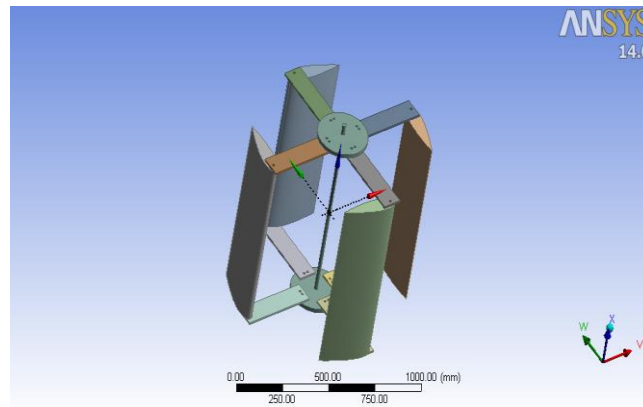


Fig 2. Model of Vertical Turbine

5.2. Meshing

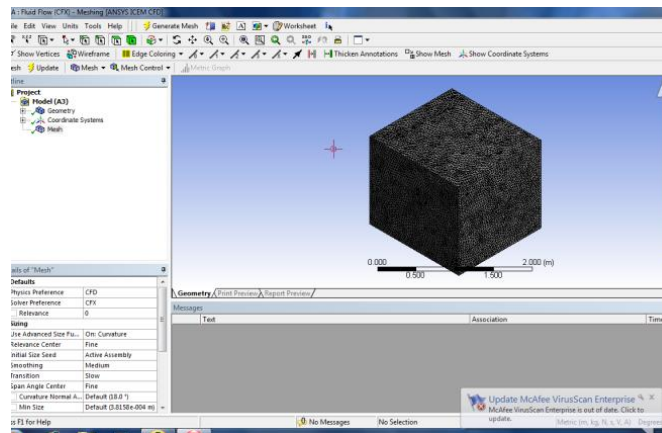


Fig 3. Meshing of Vertical Turbine

5.3. Power generation according to wind speed

The power of the wind is proportional to air density, the area of the segment of wind being considered, and the natural wind speed. The relationships between the above variables provided in equation; $P_w = \frac{1}{2} \rho A U^3$

The average wind speed to be 6 m/s. The density of air 1.204 kg/m³. Turbine 1.2 m in diameter and 1.0m high, the power of the wind is; $P_w = \frac{1}{2} (1.204) (1.2) (6\text{m/s})^3 = 156.03\text{watt}$.

Table 1

Sample	Velocity of Air [U3] [m/s]	Density of Air [ρ] [kg/m ³]	Area of wind Turbine [A][m ²]	Power output [W] [watt]
1	4.5	1.204	1.2	65.8
2	5.5	1.204	1.2	120.18
3	7.5	1.204	1.2	304.76
4	10	1.204	1.2	722.40

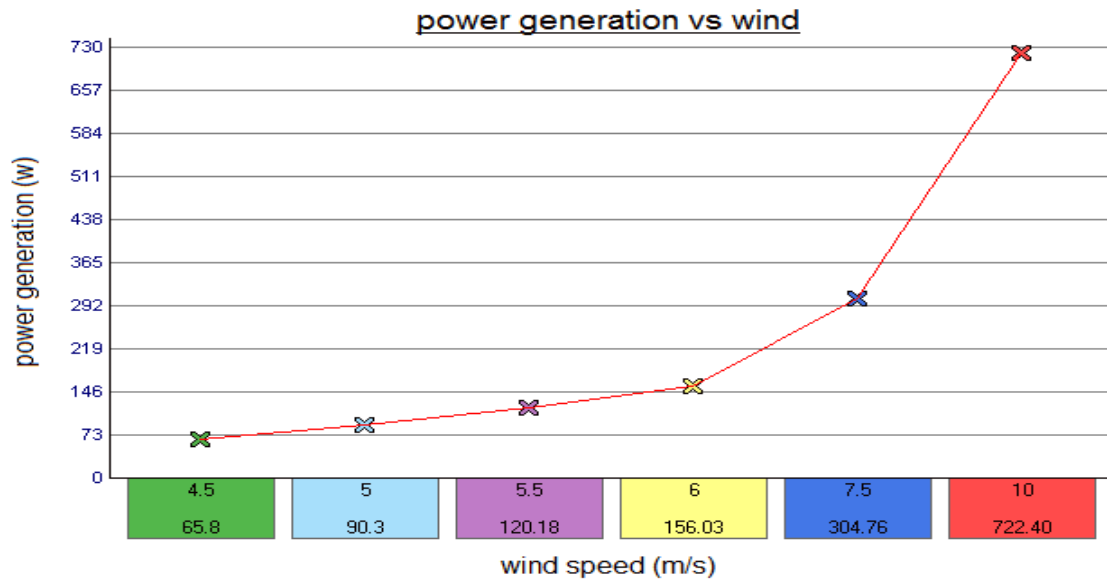


Fig 4

5.4. Coefficient of performance vs tip speed ratio

In order to test the experimental setup, the Savonius rotor was tested alone and compared to previously published from this previously published data, we expected the maximum coefficient of power (C_p) to be 0.18 to 0.20. The maximum C_p found from our experimental setup was 0.18-0.19, which is in the expected range.

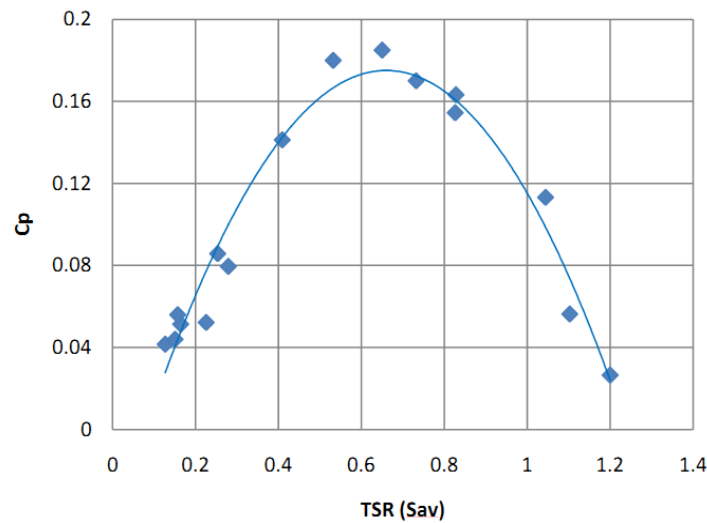


Fig 5

The coefficient of performance depends on wind speed, the rotational speed of the turbine and blade parameters such as pitch angle and angle of attack. The pitch angle for a HAWT is the angle between the blades motion and the chord line of the blade, whereas for a VAWT the pitch angle is between the line perpendicular to the blades motion and the chord line of the blade. The angle of attack is the angle between the relative wind velocity and the centerline of the blade. For fixed pitch turbines, these angles do not change and the C_p is directly related to the TSR.

5.5. Turbine speed and generator output

Turbine calculation of mechanical power output we know from the Betz coefficient that P_w cannot be obtained. Using a $C_p = 0.1$ (10% efficiency) and the value of P_w (156 w) calculated above, we can see that for a 1.2m x 1.0m turbine in 6 m/s wind at STP, the mechanical power realized is: $P_m = C_p (P_w)$

Where,

C_p – coefficient performance

P_m -- mechanical power output

$P_m = 0.1(156 \text{ W}) = 15.6 \text{ W}$

These equations can also be used to calculate the frontal area required from the output power required, wind speed, and the efficiency estimate. Then, the linear dimensions needed to support that frontal area are calculated.

Table 2

Sample	Velocity of Air [U3][m/s]	Power output Generator [W]	Power output Turbine [W]	Turbine speed [rpm]
1	4.5	65.8	6.58	62
2	5.5	120.18	12	114
3	7.5	304.76	30.47	286
4	10	722.40	72.24	687

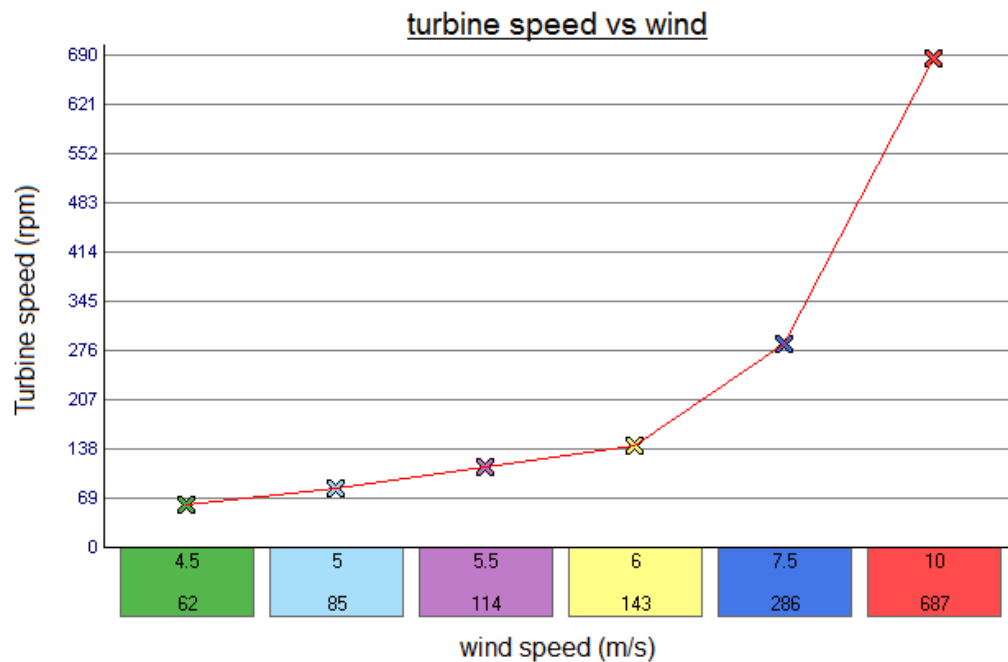


Fig 6

6. CONCLUSION

The first part of the design process, which included research, brainstorming, engineering analysis, and turbine design selection was completed during the fall term. The initial research and analysis portion of the project provided its share of complications; however, once completed it provided valuable information about the final design. To date, the major components of the turbine have been settled on, in particular, full-scale aluminum blades have been chosen, and will be machined in the CNC lab at Dalhousie. There are still some final design options that must be finalized, and these decisions will be made before turbine construction begins in early January. Testing will be a major part of the design selection, as blade profile selection will occur over the Christmas break based on prototype testing results. The test results should provide insight as to which blade profile provides the most torque and shows the most significant effects due to blade pitching. In addition to prototype testing, finite element analysis will be performed on each blade profile in an effort to confirm the wind tunnel results. The blade connectors and pitching system designs will also be finalized, and a spring selection for the passive pitching system will be made. A device used to couple the torque transducer and generator to the shaft will be designed as well. This will occur in conjunction with the selection of a generator, and design of a device that would couple the generator to the turbine after it reaches a certain rotational speed. The last item to be decided on is a brake mechanism that must be incorporated into the design for safety reasons.

Construction of the full-scale turbine will begin during the first week of the winter term, with the goal of finishing the final product by the end of February. This will allow for a month of testing and data analysis, as well as provide time for making any design alterations that are needed. A project timeline for the second term can be seen in the Gantt chart in Based on current progress, the group is confident that the final product will meet all the requirements set out in the fall term.

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